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Feeding ecology of the crowned sifaka (*Propithecus coronatus*) in a coastal dry forest in northwest Madagascar (SFUM, Antrema)

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Key words: diet, primate, activity budget, forest composition

The crowned sifaka (*Propithecus coronatus*; Milne-Edwards, 1871) inhabits dry forests, riparian forests and mangroves of northwest Madagascar. Originally believed to occur in a restricted area between the Mahavavy River in the southwest (where it overlaps with *P. deckenii*) and the Betsiboka River in the northeast (which separates it from *P. coquereli*), sightings west of the Mahavavy River and along the Bongolava Massif suggest that the distribution of this medium-sized species is wider (Tattersall, 1986; Thalmann *et al.*, 2002). The distribution and the taxonomic status of crowned sifakas have long been debated, but the combination of morphological and biogeographic evidence supports considering it as a valid species (Thalmann *et al.*, 2002; Mittermeier *et al.*, 2006; Groves and Helgen, 2007; Mittermeier *et al.*, 2008). Considered as Endangered (A2 c,d) by the IUCN (2010), populations of crowned sifakas were estimated not to exceed 1,000 individuals in the wild. However, recently discovered populations in restricted fragmented forests extend the species' distribution range farther towards the Southwest. A "Biocultural Project" was therefore initiated at Antrema (a site located in the Mahajanga region) in 2000 to promote sustainable management (Gauthier *et al.*, 2001). The project aims at

preserving a coastal environment in which crowned sifakas occur in high densities while allowing villagers, mainly fishermen, to use natural products of the environment with parsimony and to benefit from technical and economical help. The project also aims at promoting local socio-cultural rules and a way of life that tends to respect the forest environment, including useful plants and several sympatric lemur species (*Propithecus coronatus*, *Eulemur fulvus*, *Eulemur mongoz*, *Lepilemur* sp., *Microcebus murinus*). The site contains three of the Northwest's typical ecosystems (dry semi-deciduous forest, mangrove swamp, savanna), which suffer moderate anthropogenic pressure (Gauthier *et al.*, 2001). Owing to local beliefs, especially the sacred ("*masina*") nature of sifakas, the Sakalava community plays a central role in this conservation process (Harpet *et al.*, 2000, 2008). In this context, a few studies started investigating the behavior in relation to habitat and food supply of the lemur species of Antrema (Gauthier *et al.*, 1999; Razafimahefa, 2001; Ramanikirahina, 2004). However, a detailed analysis of the feeding ecology and population densities of *P. coronatus* is still lacking. We present here preliminary data on the plant species composition of the white-sand coastal forest inhabited by a dense population of sifakas (among other prosimian species) and on the feeding ecology of sifaka groups censused since 2008.

Methods

Study site

The Antrema station is a coastal area of 12,300 ha located on the left riverside of the Betsiboka estuary, northwestern Madagascar (15°42'-15°50'S, 46°-46°15'E; Gauthier *et al.*, 2001). The region undergoes a distinct dry season of 7 months from April to October. The mean annual rainfall (n = 9 years) in the Mahajanga region is 1,410 mm (with a peak in January-February), with irregular rainfall during the dry season. With an annual mean of 27° C, temperature is highest in October and lowest between June and August (Airport of Mahajanga, 2000-2009).

Although the Antrema area has been traditionally protected by the local Sakalava beliefs, forest areas where studies are conducted are fragmented. After two first surveys in November 2007 and April-May 2008, we decided to establish the study site at Badrala (15°45.665'S, 46°12.300'E). With about 20 ha just behind the littoral dune, this non-sacred forest site offers suitable conditions to study the socioecology of sifakas and the dynamics of a dry forest in Madagascar. The forest there is partly split by a sandy open dune that sifaka groups can cross easily. Tree logging occurs at low intensity (with few selected species for defined use, e.g. for boats or coffins) and small trees are sporadically cut for fences and house building. We studied floristic composition by inventorying trees along four North/South-oriented line transects, 10m-wide each, that were roughly perpendicular to the sea front. Within this 0.73 ha, we tagged each tree ≥ 10 cm diameter at breast height (DBH) with plastic labels, recorded their DBH, the number of stems and their vernacular name. Likewise, we counted woody lianas and herbaceous vines ≥ 1 m high within eight 10 x 10 m (800 m²) plots regularly spaced along the transects. Plant species were sampled and dried for later botanical identification.

Sifaka population density

In order to locate and identify groups of *P. coronatus* in Badrala, we initially mapped groups encountered during repeated transect walks. We drew individuals' facial masks for each of the followed groups, noted their sex from visual inspection of the genitalia and other external characteristics (cysts, scars, damaged ears, fur colour), and took pictures. Knowledge gained progressively of groups and individuals allowed us to provide a preliminary estimate of population density for the Badrala site.

Behavioral data collection

We collected behavioral data during 4 periods (06 to 21 July 2008; 11 November to 12 December 2008; 05 April to 06 June 2009; 17 October to 22 November 2009). Most groups were already accustomed to the sporadic presence of local people. Once we could observe animals at close distances, we followed each group successively over 2 to 5-day periods, from 06:30 to 18:30 hours.

We used the instantaneous scan-sampling method (Altmann, 1974) to study group activity budget. Every 5 minutes, we recorded the individuals' activity using one of the following categories: resting (immobile, with eyes open or closed), moving (more than 0.5 m), foraging (searching for a food item), feeding (processing or chewing a food item), social activity (displaying agonistic and affiliation behaviors with other individuals) and other miscellaneous behaviors. We noted the plant part and species eaten by individuals.

Besides recording activity budgets, we determined diet from mouthful counts converted into weight of ingested matter (Hladik, 1977) for 2 periods: April-June 2009 and October-November 2009. We estimated food intake in focal individuals that were followed continuously for 30 minutes each. Observations were alternated across males and females (excluding juveniles) within groups.

Results

Forest composition

Plant families occurring at Badrala are presented separately for trees and lianas/vines in Fig. 1. To date, 91 tree and liana or vine species have been identified at least at the family level, and taxonomic identification of 15 more putative species is still in progress. The 5 richest families in terms of the number of species are Fabaceae, Sapindaceae, Ebenaceae, Euphorbiaceae and Apocynaceae. The most dominant tree species are *Strychnos decussata*, *Vitex beraviensis*, *Mimusops occidentalis*, *Baudouinia fluggeiformis* and *Macphersonia gracilis* that represent almost one third of total basal area and tagged trees. *Combretum coccineum*, *Hypoestes* sp., *Landolphia perrieri* and *Reissantia* sp. accounted for more than one third of the lianas and vines.

Density of trees inventoried on the 4 transects (n=486) corresponds to 666 inds. ha^{-1} with a total basal area of 14.5 m² ha^{-1}. We found a high density of woody lianas and herbaceous vines in the 800m² plots (n=373).

Sifaka population density and group composition

Groups at Badrala have 1-3 breeding adult males, 1-4 breeding adult females, and 1-4 immature offspring. We encountered between 15 and 20 groups at this site. Based on current recognition of individuals within these groups, a minimum estimate of 300 inds. km² was calculated. Mean size of focal groups was 4.3 ± 1.8 individuals (n=16).

Diet and activity pattern

Sifakas consumed at least 60 plant species from 32 families. Tab. 1 lists major food species eaten. During the dry season, 14 plant species represented 75 % of the diet whereas only 7 species were the main food resource in the wet season. Sifakas were highly folivorous during both seasons, supplementing their diet with flowers, fruits, vegetative

Tab. 1: Food species accounting for 50 and 75 % of the diet of *Propithecus coronatus* during the dry season and the wet season. Eaten plant species are listed in decreasing order and their abundance in transects and plots (see text) is indicated.

Family	Species	Vernacular name	Items	Abundance (%)		
Dry season						
Lamiaceae	*Vitex beraviensis*	Mojiro	*yl*	10,7		
Fabaceae	*Baudouinia fluggeiformis*	Manjakabentany	*yl ml*	4.7		
Sapotaceae	*Mimusops occidentalis*	Natofotsy	*yl stems*	3.9		
Anacardiaceae	*Operculicarya gummifera*	Atokonjo	*ml buds*	3.5	50 %	
Sapindaceae	*Majidea zanguebarica*	Tsipopoka	*yl ml fl*	2.3		
Oleaceae	*Noronhia boinensis*	Tsilaitra beravina	*yl*	1.9		
Moraceae	*Trilepisium occidentalis*	Kililo	*ml*	1.2		
Sphaerosepalaceae	*Rhopalocarpus lucidus*	Hazondringitra	*yl fr*	1.0		
Melastomataceae	*Warneckea* sp.	Voatrotrokoala	*yl*	0.6		75 %
Burseraceae	*Commiphora* sp.	Arofy	*fr buds*	0.4		
Fabaceae	*Bussea perrieri*	Morango	*ml*	0.2		
Olacaceae	*Olax dissitiflora*	Ambiotsy	*ml*	0.2		
Moraceae	*Ficus pyrifolia*	Nonika	*fr*			
Unidentified	-	RR80	*ml*			
Wet season						
Anacardiaceae	*Abrahamia deflexa*	Motsovavy	*yl fl*	3,1		
Anacardiaceae	*Abrahamia* sp.	Manavodrevo	*buds yl fl*	1.2		
Fabaceae	*Chadsia flammea*	Fanamohazo	*buds yl fl*	0.8	50 %	
Sapotaceae	*Capurodendron gracilifolium*	Natoboay	*buds yl fr*	0.2		
Apocynaceae	*Landolphia perrieri*	Vahipira	*yl*	6.8		75 %
Combretaceae	*Terminalia* sp.	Taly	*buds yl*	3.1		
Anacardiaceae	*Operculicarya gummifera*	Atokonjo	*yl*	3.5		

yl: young leaves; ml: mature leaves; fl: flowers; fr: fuits

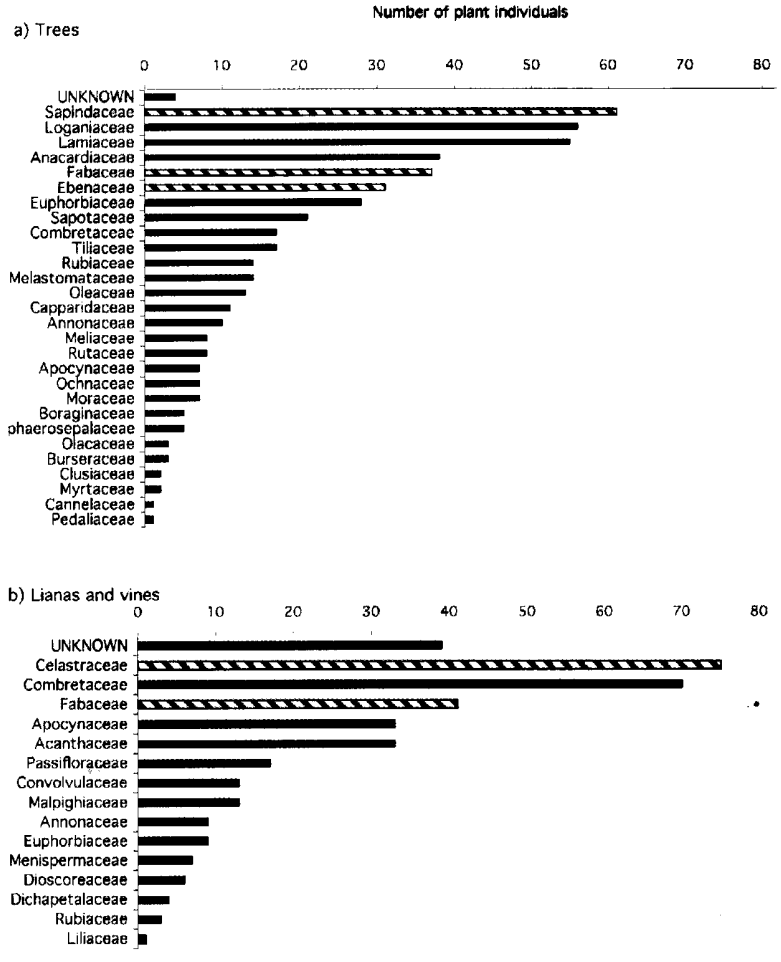

Fig. 1: Abundance of plant families plotted in decreasing number of individuals among a) trees with DBH>10cm (based on transects; 0.73 ha) and b) woody lianas and herbaceous vines >1 m height (based on plots; 0.08 ha). Striped bars refer to the plant families with the highest number of species.

buds, and sometimes young stems (Fig. 2). They consumed more mature leaves and fruits in the dry season and more flowers in the wet season.

The activity budget of the sifakas is presented in Fig. 3. Although 'resting' predominated throughout the study, individuals rested more in the dry season than in the wet season. ~~Inversely, they~~ travelled and engaged in feeding activities more often during the wet season.

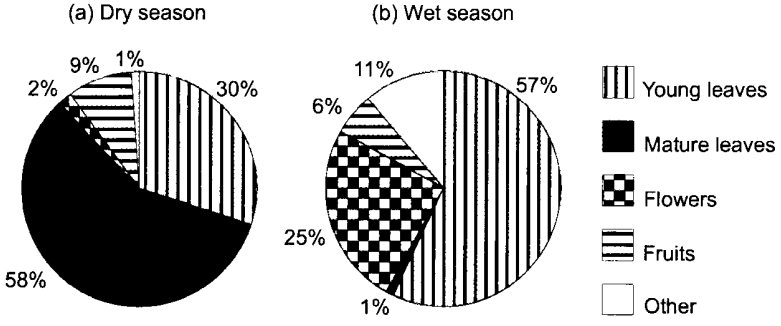

Fig. 2: Food categories in the diet of *Propithecus coronatus* during the dry season (a) and the wet season (b).

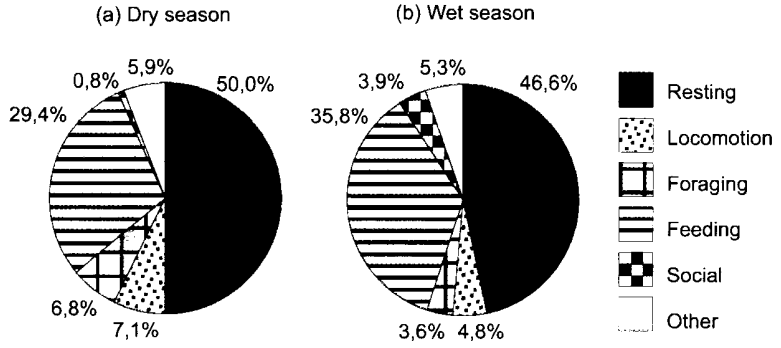

Fig. 3: Activity budget of *Propithecus coronatus* during the dry season (a) and the wet season (b).

Discussion

The sifaka density was found to be high in the dry forest of Antrema, with a minimum estimate far above the 173 inds. km² found in the riparian forest of Anjamena (Muller *et al.*, 2000) or for other sifaka species in dry or wet forests (O'Connor, 1988; Ganzhorn, 1992). This high density might be related to some peculiar characteristics of the forest in terms of food quantity and/or food quality available to this prosimian species. However, tree basal area was not particularly high compared with other dry forests in Madagascar and Mayotte (Hladik, 1980; Simmen *et al.*, 2005). It is not yet clear also whether high density is related to a putative low predation pressure. To our knowledge, no sightings or traces of viverrid carnivores have been reported; large raptors and boas would be the only predators that could affect the demography of the Antrema sifaka population (Garbutt, 2007; Sinclair and Legrand, 2008).

As regards their feeding behavior, crowned sifakas fed primarily on leaves from a few tree, liana and vine species, and supplemented their diet with a wide range of secondary items as commonly occurs in other *Propithecus* species (Meyers and Wright, 1993; Simmen *et al.*, 2003; Lehman and Mayor, 2004; Irwin, 2008). Although this species remained folivorous during our study, its diet changed with seasons. Young leaves were the preferred food type in the early wet season, while mature leaves were the dominant one in the beginning of the dry season. In addition, *P. coronatus* ate a higher proportion of liana and vine parts during the wet season. Crowned sifakas also followed the typical activity pattern of other sifaka species (Norscia *et al.*, 2006; Patel, 2006; Charrier *et al.*, 2007), spending most of their time resting and devoting a substantial amount of time to feeding activities and locomotion. Activity budget nevertheless changed with seasons. It is generally suggested that the cool dry season represents a period of food scarcity for animals, which they compensate for by reducing their energy expenditure, travelling less and resting more. In a recent joint research project, the content of litter traps regularly distributed along the transects was collected and weighted every two weeks throughout one year. It was found that plant species could be grouped according to their temporal pattern of leaf loss (Ranaivoson *et al.*, 2010; see also Razakanirina, 2010). Several trees, lianas and vines lost their leaves more or less regularly throughout the dry season while others were characterized by delayed leaf loss or on the contrary by precocious leaf fall. One consequence is that leaves are available throughout the year, although as different sets of species varying in quantity, diversity, and presumably, nutritional quality. This at least could explain why sifakas are able to increase the diversity of consumed plants (and adopt a more opportunistic strategy) during the dry season, a period normally described by the scarcity of food resources.

Future work on seasonal variations in the diet's nutritional and chemical content will allow us to examine the role of qualitative aspects in food choices (Moss, 1991; Dearing *et al.*, 2000) and further examine potential differences between genders with regard to the importance of energy conservation for female sifakas (Wright, 1999; Charrier *et al.*, 2007).

Conclusion

Better knowledge of the ecology and the villagers' social perception of this flagship species may contribute to conservation of other diurnal lemurs, by incorporating the villagers' symbolic perception of their natural environment. Investigating the interactions between this species and plants of the coastal dry forest ecosystem will undoubtedly result in better conservation decisions for Antrema. From an evolutionary ecology standpoint, the studies we have planned for the next years at Antrema will also contribute to better identify the selective pressures that have been driving the evolution of prosimian typical life-history traits such as reproductive synchronization or dominance-based feeding priority of females over males in gregarious species (Wright, 1999; Dewar and Richard, 2007).

Acknowledgements

We thank the Malagasy Institutions that authorized to collect and export the plant samples, the Ministère de l'Environnement, des Eaux et forêts et du Tourisme. We also thank Antrema's project staff for assistance with the field work as

well as Master degree students S. Razakanirina, T. Ranaivoson, V. Randriantoposon and L. Razafindramahatra for helping with data collection. Special thanks to the specialists of the Dept of Phanerogamy, J.N. Labat, P. Phillipson and Pete Lowry, for helping with plant identification. Finally, we thank C.A. Gauthier, E. Roger, D. Rakotondravony and H. Razafindraibe for logistic support and collaborative work, and E.G. Leigh for helpful comments on an earlier draft. This study was funded by the UMR 7206 - CNRS, and was conducted under the "Convention cadre de cooperation" between the Université d'Antananarivo and the Museum National d'Histoire Naturelle, Paris.

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